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THE USE OF ERTS-1 TO MORE FULLY UTILIZE AND APPLY MARINE STATION DATA TO THE STUDY AND PRODUCTIVITY ALONG THE EASTERN SHELF WATERS OF THE UNITED STATES

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16. Abstract

Sea truth data was obtained during two ERTS overpasses in waters near the entrance of the Chesapeake Bay. Correlations were made between total phytoplankton and chlorophyll values (among other parameters) in these waters to radiance detected by ERTS in an effort to map areas of similar productivity levels. Band 4 radiance had the highest correlation to all parameters with bands 5 and 6 showing decreasing correlations in each case. The radiance values were apparently influenced by one or more factors, most likely including the sediment content of the water. The data have shown that ERTS MSS is not suitable for monitoring chlorophyll in near-shore waters where sediment loads are high. It is suggested that in more seaward or pelagic locations, that ERTS MSS would be more efficient in monitoring surface chlorophyll values and establishing direct relationships to phytoplankton concentrations.

The composition of phytoplankton is also given for two cruises in the western north Atlantic and in collections taken off the entrance to Chesapeake Bay.

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PREFACE

The objective of this study was to utilize ERTS-MSS data to monitor chlorophyll levels related to phytoplankton concentrations in coastal waters of the eastern United States. It was found that ERTS-MSS was not suitable for monitoring chlorophyll in near shore waters where the sediment loads were high. The application of ERTS-MSS to seaward or pelagic locations should be more feasible due to less interference in the monitoring of surface chlorophyll values and more direct relationships to phytoplankton composition.

INTRODUCTION

The original plan in this study was to utilize several vessels in existing programs to obtain water samples and pertinent data from the eastern shelf waters of the United States. These ongoing operations included the Groundfish Survey Program, the International Commission for the Northwest Atlantic Fisheries (ICNAF) collections, and the Marine Resources Monitoring Assessment and Prediction (MARMAP) cruises, which were operated under the National Marine Fisheries Service and the U. S. Coast Guard. These programs made available the opportunity to sample during each seasonal cruise over 100 sea stations located in and beyond the continental shelf waters between Nova Scotia and Florida. At these stations water samples were obtained for the determination of phytoplankton composition and density. Such information was used to ascertain the seasonal population densities and distribution patterns of the phytoplankton in relation to specific ecological variables. The relationship of such high and low phytoplankton concentrations to marine waters of high and low productivity values has been well established and was the fundamental premise upon which this investigation was based. The major link between the actual phytoplankton concentrations in these studies and a recordable variable related to the phytoplankton populations that was capable of being detected by the ERTS sensory unit was the total chlorophyll in the surface waters. The premise followed that if a correlation could be made between the sea truth data collected (which included total chlorophyll and the total phytoplankton) and the radiance values detected by ERTS, a synoptic mapping for a productivity index could be subsequently ascertained for the entire eastern coastal water areas off the United States.

The test site for the present study included an area that extended from Cape Cod to Charleston, South Carolina. Roughly shaped like a parallelogram, the western border followed the eastern coastal shoreline paralleled by the eastern margin which ranged from 120 to 300 miles seaward (north to south). A large portion of this more eastern segment of the site area was

beyond the continental shelf and in the open waters of the western North Atlantic Ocean.

During the projected life span of the satellite, several of the above-mentioned programs included planned cruises over the test area. These involved cruise tracts of 300-400 miles along the east coast and several hundred miles seaward. These cruises would normally last between 30 and 40 days. To utilize these vessels in this project, the original plan called for collections to be made at sea during those cruises which coincided with the ERTS overflights. At each sea station water samples would be taken for quantitative and qualitative determinations of the phytoplankton, total chlorophyll values, salinities, and temperatures. With several cruises planned for this period, seasonal differences in plankton abundance and relationships to different currents, estuaries, and coastal sections would be sought. An additional benefit of this series of investigations would be the total phytoplankton information obtained from all the stations. This would offer significant data concerning distribution patterns of species over a broad section of marine coastal waters in the western North Atlantic.

Two cruises were planned to be utilized during the first six months of the study (Figure 1). These were in the MARMAP program with vessels of the National Marine Fisheries Service having scheduled summer and winter cruises. The R/V DELAWARE II was at sea from July 12, 1972 through August 13, 1972 (cruise 72-19) making collections between the Gulf of Maine and Florida. Unfortunately the delay in the initial launch of ERTS and its subsequent late start in data acquisition resulted in a failure to have the ERTS overflight orbits correspond to ship locations from this cruise. The original flight would have coincided with excellent ship positions during the first week at sea. The cruise tract of the vessel was committed, so no later alteration could be made to relate re-positioning of the vessel to the modified flight plan of ERTS. Results for this series of collections were limited to an extensive series of water collections, where plankton composition was later determined to plot distribution patterns for representative species. The results of 40 sea stations were analyzed for this synopsis. In addition, at each of the stations chlorophyll values were determined, with salinity and temperatures recorded. However, no correlation to ERTS was possible for this cruise.

The winter cruise of R/V ALBATROSS IV (cruise 73-2) was scheduled for the period January 18, 1973 through February 28, 1973. The original cruise tract called for sampling to begin and continue along the eastern coastal waters from the Cape Cod area southward. Knowing the overpass times for consecutive orbits of ERTS, a sampling procedure was designated aboard the vessel for these dates. Collections of sea truth data were to be obtained between January 22-26, 1973 and February 10-15, 1973. Forty sea stations were established for these time periods. Unfortunately, an altered cruise tract, brought on by unforeseen circumstances, resulted in the placement of the vessel out of the overflight areas and no coordinated sampling with ERTS was possible. However, phytoplankton composition, chlorophyll, and physical data were still obtained at 40 sea stations during this cruise.

The problems associated with coordinating the ERTS overflights to these extensive sea truth collecting programs became obvious. Such cruises were planned 6 to 8 months in advance with only brief periods for possible simultaneous data retrieval. Storms at sea, extensive cloud cover, or simple problems at sea could easily cause an alteration of the original cruise tract, or delay the vessels departure date and affect the ship's position. In order to offer a more flexible and additional collecting opportunity at sea, the Old Dominion University research vessel LINWOOD HOLTON and privately owned water craft were used to obtain sea truth information during other periods of ERTS overpasses. This vessel was first used in the program on January 26, 1973 and on subsequent ERTS overpass days. Such dependence on local vessels for data proved necessary, as other anticipated cruises in the various Marine Fisheries Services programs were either curtailed or eliminated due to federal budgetary reductions.

The R/V HOLTON was used on 16 days that coincided with overpass periods for ERTS. Collections were made between January 26, 1973 and September 17, 1973. Originally three stations were established off the entrance of the Chesapeake Bay extending seaward over the shelf. Later a fourth station was added (Figure 2). The most seaward extent of these stations was 15 miles. At each station water samples were taken for phytoplankton and chlorophyll analysis, surface temperature, and salinity.

COLLECTION AND ANALYTICAL METHODS

For each of the cruises, the phytoplankton samples were collected in 0.5-liter polyethylene bottles and preserved with a buffered formalin solution. A settling period and siphoning procedure followed, that resulted in a 40-ml concentrate of the original sample. This was placed in a settling chamber for subsequent examination with a Zeiss inverted plankton microscope. Phytoplankters were identified and species concentrations noted in numbers of cells per liter. Separate 1-liter water samples were collected for chlorophyll determinations. These were stored in an ice chest with the chlorophylls subsequently determined according to procedures given in the Unesco publication on the "Determination of Photosynthetic Pigments in Sea Water" (Parsons, 1966). A Gilford Model 240 Spectrophotometer was used for optical density measurements. Isodensity traces were made of the ERTS Positive Transparencies for the various bands. Using a Joyce Lobel Microdensitometer, isodensity traces were then matched with the sea truth data at station points for correlations to actual values determined for chlorophyll at these sites. Since chlorophyll values alone are not considered a valid index for mixed populations of phytoplankters, a more accurate correlation was sought in this investigation by including with the actual chlorophyll values the phytoplankton composition and densities present.

Utilization of the research vessel DELAWARE II during July and August 1972 and the ALBRATROSS IV in January and February 1973 did not provide corresponding ERTS sensory information to sea truth data. This was due to the delay in the ERTS launch date in July 1972, and a changed cruise tract for the vessel in January 1973. The MARMAP program provided too little flexibility in attempting to coordinate the two separate operations. The utilization of a locally based vessel proved to be the most appropriate alternative in relation to more flexible ship scheduling and financial restraints.

The R/V LINWOOD HOLTON was utilized on January 26, 1973 for water samples and sea truth data. A repeated pattern of collections began on March 21, 1973 through September 17, 1973, where water samples were taken along a transect that extended seaward 15 miles off the entrance of Chesapeake Bay. A total of 16 collections cruises were made in the test area during periods of ERTS coverage. Cloud cover was extensive and not suitable for subsequent data analysis on 14 of these dates. Suitable skies were available on January 26, 1973 and August 12,

1973 when the vessel was collecting samples. Another clear day occurred on February 13, 1973 but the vessel was not available at that time. Based on the two successful dates, seven data points (stations) were available for further analysis. The discussion of the phytoplankton composition and other data obtained during these cruises is presented in the Appendix with corresponding information given in Tables 1 through 10.

Correlation of Water Parameters

The correlation of each water parameter with the other parameters for the three separate collection programs (cruises) is presented in Table 11. Note that the predominantly northern stations were visited by the DELAWARE II in summer while the southern stations were sampled by the ALBATROSS IV in winter. The correlation between phytoplankton (total number) and chlorophyll ranges from 0.82 for the DELAWARE II stations to 0.21 for the ALBATROSS IV stations. Whether this is a seasonal or latitudinal variation cannot be determined. However, it has already been stated that species diversity and the amount of chlorophyll per species should cause an appreciable variation in the correlation between chlorophyll and phytoplankton.

Another interesting trend is the correlation between chlorophyll and salinity, which varies from -0.81 for the DELAWARE II stations to 0.15 for the ALBATROSS IV stations. The correlation between chlorophyll and temperature, on the other hand, varies from -0.68 for the ALBATROSS IV to 0.03 for the DELAWARE II. Once again the lack of seasonal data prevents one from determining the real significance of the correlations.

Correlation of ERTS Photography with Water Parameters

The only successful ERTS overflights occurred on January 26 and August 12 for the LINWOOD HOLTON cruises. A sketch of the Chesapeake Bay entrance showing the station locations for these two days is given in Figure 2. Figure 3 is an MSS band 6 image of the area. The coordinates of the stations are given in Table 12, along with a summary of the water sample analyses. The four stations visited on August 12 are the same for all other days.

The radiance values for each MSS band were extracted from the 9-inch positive transparencies. This data is presented in Table 13, where it is noted that band 7 was not available for August 12. The zero radiance values for bands 6 and 7 on January 26 indicate that the output of the microdensitometer had reached the noise level of the film.

The correlation between the independent variables is given in Table 14 for each day and for the combined data. Unlike the analysis presented earlier for all of the LINWOOD HOLTON data, chlorophyll and phytoplankton show a high correlation (0.85 to 0.95). The chlorophyll and salinity data have a high negative correlation (-0.92) for August 12; no data were available for January 26.

Correlation between the water parameters and MSS radiances for each band and each ratio of two bands, for each day separately and for the combined data, is given in Table 15. In the combined analysis, the radiance values were corrected for sun angle variations by dividing the radiances with the cosine of the solar zenith angle. A linear regression was performed for each data combination, with the water parameter taken as the independent variable. A plot of the combined data for each water parameter versus band 4 radiance values, along with the linear regression line, is presented in Figures 4 through 7.

Figures 8 and 9 are "isophots" of bands 4 and 5 images, respectively, for August 12. The isophots were produced by scanning the image with a microdensitometer which has been modified so that it (a) makes automatic programmed, precisely-positioned, successive scans across a specimen (rather than a single scan); and (b) prints out the density information in coded format on a plot. The printout pen changes its mode of writing whenever the density of the film changes by a small discrete density increment. As the density along a scan decreases, the pen writes a solid line until the limit of this discrete density increment is reached. Then it writes a series of equally spaced dots until the next increment is reached. The pen lifts up and leaves a blank for the next increment. The pattern, line-dots-blank, is repeated as long as the density is decreasing. When the density is increasing, the pattern is reversed, blank-dots-line. The use of three printout symbols makes it obvious whether the density is decreasing or increasing as the mode changes. When the area of interest on the film has been completely plotted by successive scans of equal distance, the discrete density increments line up beside each other. The patterns thus generated are analogous to the isobar lines on a weather map and called "isophots". Each continuous area represents densities within a small, discrete range. A line tracing the boundary between two contiguous areas is an isodensity trace.

By associating a given density (or radiance) with the chlorophyll value for each of the four stations on August 12, a chlorophyll contour map of the Bay entrance is obtained (Figure 10). This assumes that the correlation between chlorophyll and band 4 radiance is valid; further discussion of this point is given below.

DISCUSSION OF RESULTS

Band 4 radiance had the highest correlation with all parameters, with bands 5 and 6 showing decreasing correlation in each case. The correlation between band 4 and chlorophyll for the two days was 0.90 and -0.82. Although the chlorophyll correlations are good, the slope of the linear regression line is positive on one date and negative on the other. Whereas chlorophyll decreased away from the coast on both dates, radiance decreased on January 26, but increased on August 12. Combining the data simply reduced the correlation (-0.32).

It is clear that the radiance values are being influenced by some other parameter(s), the most likely candidate being sediment. Bowker and Witte (1975) have found that suspended sediment correlates well with radiance in the lower Chesapeake Bay area. Yarger, et al. (1973) found band 4 to be useful for sediment determinations below 80 mg/l, and since the suspended sediment concentrations were less than 5 mg/l on January 26, this could explain the variations in slope given here. The change in the sediment patterns on these two days is probably related to the tide. On January 26 ERTS 1 passed over the area about an hour after the beginning of flood tide. The relatively clear ocean waters are being carried into the Bay, and it is reasonable to assume that the sediment concentrations would be highest near shore and decrease seaward. On August 12 the ERTS-1 overpass occurred about 1.5 hours after the beginning of ebb tide. Thus, sediment is likely to increase seaward due to the passage of the sediment-laden Chesapeake Bay plume.

Phytoplankton showed the same correlation trends as chlorophyll, as expected. The total number of phytoplankton, which varied from 16,000 to 70,000 cells per liter, were apparently insignificant compared to the total particle count which ranges as high as 10^9. Yost, et al. (1973) found the same conditions for the New York Bight area.

Temperature only varied 1°C on each day, and thus it is difficult to draw any conclusions regarding the correlation results, which were not consistent.

Salinity was only monitored on August 12, and the correlation with band 4 was 0.97. Since band 4 radiance is apparently dominated by sediment, this might indicate a linear relation between salinity and sediment. It is more likely that this is controlled by tide which is responsible for the discharge of the Bay waters. When the flow of water is into the Bay, the correlation between salinity and sediment will probably become negative.

CONCLUDING REMARKS

In general, an analysis of the data have shown that the ERTS MSS is not suitable for monitoring chlorophyll in near shore waters where sediment loads are high. However, several authors have demonstrated ERTS potential for monitoring sediment (or particulates). During this study it was found that chlorophyll usually decreased away from the coast and, except for where the Bay waters enter the Atlantic and are carried south, sediment behaved the same way. However, it is not clear just what the relation is between the sedimentary environment and chlorophyll. Sediment certainly influences the photic zone and is also quite often associated with nutrients which are important for the growth of plankton. The various upwelling and current actions that would increase the sediment composition within the water column would also reestablish any settled phytoplankton back into the water. As collections were made seaward the degree of this upwelling over the shelf generally decreased with an accompanying change in the phytoplankton composition from the non-motile diatom dominance to that of phytoflagellates. These motile forms are not only of smaller size, but offer considerably less chlorophyll per unit area of sea surface. Further application of the ERTS synoptic view of coastal waters will provide significant information not only on turbulence phenomena, but should include an understanding of the relationships of this activity to areas of specific productivity values. The application of additional ERTS MSS studies to the more seaward or pelagic locations should allow for less interference in the monitoring of surface chlorophyll values and more direct relationships to phytoplankton composition.

APPENDIX

DELAWARE II Cruise 72-19: Phytoplankton Observations

A total of 60 phytoplankters were identified from this cruise (Table 1). There were 34 diatoms, 16 pyrrhophyceans, 3 cyanophyceans, 2 silicoflagellates, and 5 coccolithophores recorded. The diatom populations were dominated by several species. These included *Cyclotella glomerata, Fragilaria crotonensis, Leptocylindrus danicus, Melosira* spp., *Rhizosolenia* spp., and *Thalassionema nitzschioides*. Highest concentrations were noted at each of the near shore stations where the diatoms were found in greatest numbers. Of the offshore stations, the one having the highest total phytoplankton (and the lowest salinity reading) was located outside the entrance to the Chesapeake Bay estuary (station #76). Here the concentrations reached 1.5 million cells per liter. The majority of these were the diatoms *Cyclotella glomerata* and *Thalassionema nitzschioides*. The diatom concentrations declined at the more seaward stations. There was a tendency for fewer diatom species represented, and lower concentrations at the open stations in the lower latitudes. These would be in reference to those stations between Cape Hatteras and Jacksonville in comparison to those north of Cape Hatteras to Cape Cod.

The most numerous pyrrhophyceans included *Amphidinium* sp., *Ceratium* spp., *Exuviaella apora, Peridinium* spp., and *Prorocentrum* spp. The highest concentrations of these phytoflagellates also occurred at the near shore station. Generally, there was a decrease in the total numbers and diversity of these forms at more seaward stations, where their total numbers were greater than the diatoms. This conforms with previous studies in this area reported by other investigators (Hulburt, 1962; Marshall, 1971).

The silicoflagellates, *Dictyocha fibula* and *Distephanus speculum*, were noted at stations mainly south of the Chesapeake Bay. They were never numerous. The cyanophyceans were represented by three species: *Johannesbaptistia pellucida, Oscillatora* sp., and *Trichodesmium thiebautii*. Of interest are the high concentrations of the *Oscillatora* sp. at several pelagic stations. There was an apparent concentration of this species in an area of about 100 square miles located between 38° and 40° north latitude and about 100 miles southeast of Long Island. Large numbers of trichomes were common in all collections from this area. The only offshore station where the cyanophyceans were abundant was located off Savannah. In addition to above categories, there were numerous coccolithophores observed in the samples. Due to their small size and the need of electron microscopy for a complete systematic coverage of this group, no quantitative data of the coccolithophores have been included in this study. However, the species identified included the following: *Cyclococcolithus leptoporus, Discosphaera tubifera, Gephyrocapsa oceanica, Coccolithus huxleyi,* and *Syracosphaera pulchra*. Other unidentified nannoplankters were noted in many of the samples. These were found at both the near-shore and more seaward stations.

The relationships of numbers of phytoplankton cells per liter to chlorophyll values often are misleading. The cells of the various species of phytoplankters vary greatly in size and in the total amount of chlorophyll each cell would contain. Such relationships would have a more significant correlation if values for unicultural concentrations were to be used. At sea, the species diversity may frequently be great, yet the phytoplankton numbers will remain dominated by one or two species. Under these conditions, a more reliable correlation would be expected between the total number of cells and chlorophyll A values. Table 2 indicates the chlorophyll values and the total phytoplankton counts per liter for each of the collection stations. Numerous discrepancies are apparent: e.g., at Station 3, 2400 plankton cells per liter and 0.3784 mg per m^3 were recorded, whereas, Station 114 had 72,000 cells per liter, yet a chlorophyll concentration of only 0.1978 mg per m^3. Highest values for both cell counts and chlorophyll A were noted at Station 76, when 1.5 million cells and 8.1528 mg of chlorophyll per m^3 were recorded. The greatest concentration of chlorophyll occurred at near-shore stations where upwelling actions may have introduced

detrital material and other chlorophyll containing contaminants into the sample. This may have enhanced the chlorophyll values at these sites (Table 2).

ALBATROSS IV Cruise 73-2: Phytoplankton Observations

A total of 44 phytoplankters were identified at stations from this cruise (Table 4). There were 21 diatoms, 13 pyrrhophyceans, 3 cyanophyceans, 6 coccolithophores, and 2 silicoflagellates. The coccolithophores that were able to be identified with light microscopy included *Discosphaera tubifera, Calciosolenia murrayi, Syracosphaera pulchra, Coccolithus huxleyi, Cyclococcolithus leptoporus,* and *Rhabdosphaera stylifer.*

The sites visited during this cruise were mainly pelagic stations with several scattered within passages of the Bahama Island group. The salinity values were accordingly all above 36.0‰. These collections consisted of mainly pelagic species, found in low concentrations and with little species diversity at each station. This generalization was also true for each of the stations in close proximity to various islands within the Bahama Island chain. The highest concentration was 47,200 units per liter recorded for an open water station (No. 5), being over 180 miles north of the Bahama Islands. In this particular sample the main bulk of the phytoplankton count was attributed to the trichomes of the cyanophycean *Trichodesmium hildebrantii.* The collections followed two transects, both in a north-south direction; one was from 50 to 120 miles east of the U. S. coastline, the other was farther eastward, over 480 miles beyond the U. S. shore. In the first transect the diatoms predominated, with *Chaetoceros* spp. and *Melosira* spp. the major groups present. The pyrrhophyceans were present in lesser concentrations with *Peridinium* spp. and coccolithophores common. In contrast, samples taken at more seaward-located stations of the second transect had fewer diatoms species and an increase in the phytoflagellate species and their concentrations. The major diatom group was the *Melosira* spp., whereas *Oxytoxum* spp., *Peridinium* spp., and other phytoflagellates were more abundant at these stations.

The chlorophyll concentrations and temperature and salinity values for stations in this cruise are given in Tables 6 and 5 respectively. Lowest values were recorded for the stations of the second transect, located farther at sea from the United States coastline. These values were lowest in spite of high concentrations of cells recorded for several of the stations (Stations 5, 11, 15). The higher chlorophyll concentrations were associated with stations from each transect with similar cell numbers; Station 15 had a count of 15,600 cells per liter with a chlorophyll reading of 0.08 mg/m^3. Yet at Station 49 there were 16,400 cells per liter with a chlorophyll reading of 0.26 mg/m^3. Both stations contained a concentration of similar sized cells, in about the same ratio of diatoms and phytoflagellates. Station 49 was located about 75 miles offshore and at 850 meters of depth. It is most probable that suspended detrital material introduced from upwelling actions over the continental shelf augmented the chlorophyll values for this station and others along the transect.

LINWOOD HOLTON Cruises: Phytoplankton and Chlorophyll Observations

Water samples were taken on 10 separate collection trips aboard the LINWOOD HOLTON east of the entrance to the Chesapeake Bay. Five other trips had to be cancelled due to either severe weather conditions or the unavailability of the vessel. The three stations selected for January 26, 1973 were located along a transect off Cape Henry from Red Buoy No. 2 to the Chesapeake Light, located about 14 miles from shore (Figure 2). During subsequent trips a fourth station was added at Red Buoy No. 6, located within the Bay (Thimble Shoal) entrance channel between Cape Henry and the Bay bridge-tunnel system. Thus, Stations 1, 2, 3 for January 26, 1973 refer to those progressing from the shore seaward. Stations have been redesignated for subsequent collections (e.g., 1, 2, 3, 4) with Station 1 referring to the Bay entrance site and progressing seaward to the Chesapeake Light.

The dominant phytoplankter groups are given in Table 9. This is not a complete list of phytoplankton for these stations, but only representative of those forms that made up the majority of cells under the diatom and pyrrhophycean categories. A more complete seasonal listing of phytoplankters

for this location and adjacent coastal areas will be published elsewhere. The category "other" in Table 10 refers to the unidentified nannoplankters present in most plankton samples. These consist mainly of chlorophyll containing cells, less than 3-5 μm in size, with most of them flagellated. They may represent fully mature cells or the developmental stages of other forms in the area. Due to their significant numbers, they are a major contributor to the food chains and overall productivity of a region.

As with other offshore stations near an estuary, the total concentration of phytoplankters is high in comparison to open sea stations. The species diversity and the total numbers of phytoplankter units were greatest near shore, and decreased seaward. There was a distinct pattern of greatest numbers of cells and highest chlorophyll values at Stations 1 and 2 over the period of study. The Chesapeake Light, which represented the farthest station from shore (15 miles), consistently had the lowest chlorophyll values. The relationship between chlorophyll concentrations and phytoplankton cell members was not clearly represented. The magnitude of variation was generally larger than what would be anticipated at the nearshore stations for chlorophyll. This was true even where comparisons were made at stations having the phytoplankton populations composed of similar species. Closer relationship between chlorophyll values and total phytoplankton concentrations were more apparent at Stations 3 and 4 for the various transects. A possible reason for the increased chlorophyll values at Station 1 would be the upwelling action and the subsequent enrichment to the water column with detrital material and phaeophytin. This would then produce a chlorophyll value not truly representative of the phytoplankton population present. Although the influence of tidal exchange and this upwelling condition would extend beyond Stations 3 and 4 over the continental shelf, the influence of the true chlorophyll concentrations of the plankters should diminish.

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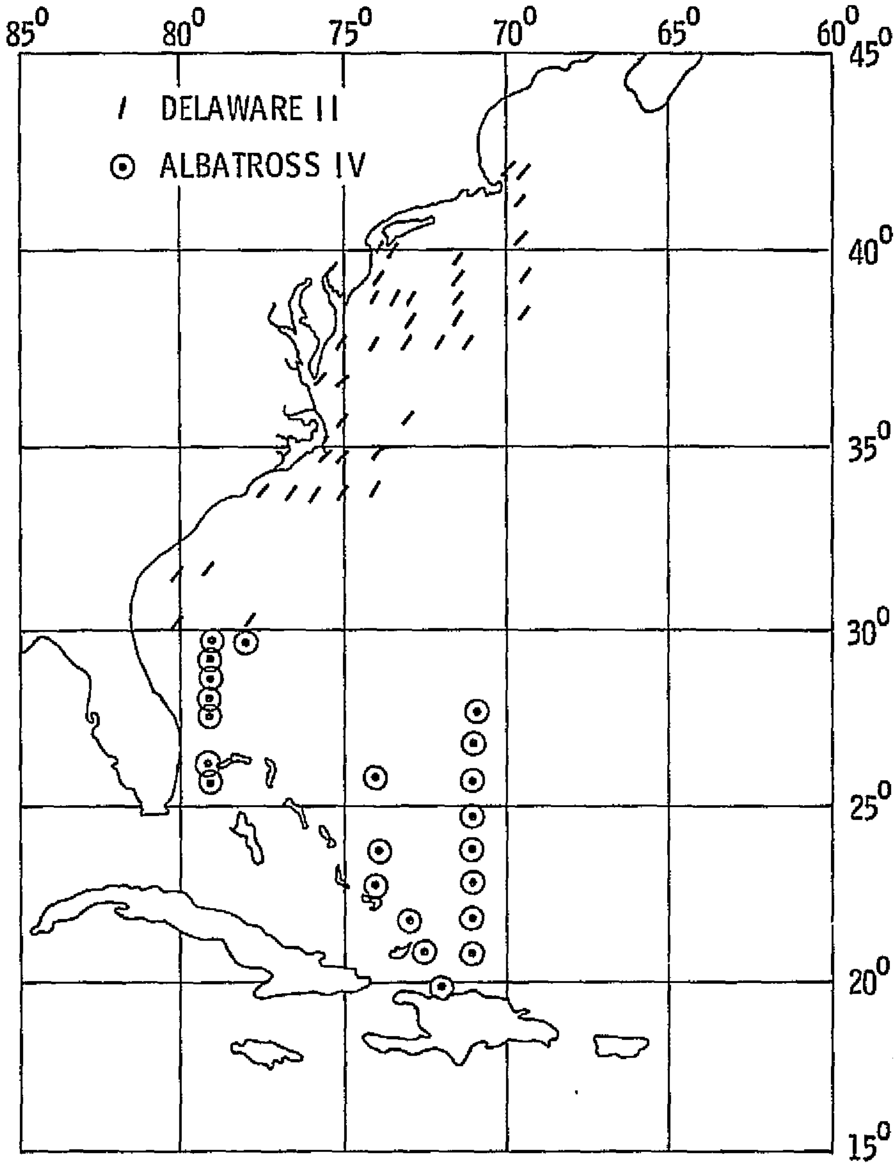

Figure 1. MARMAP sea station locations.

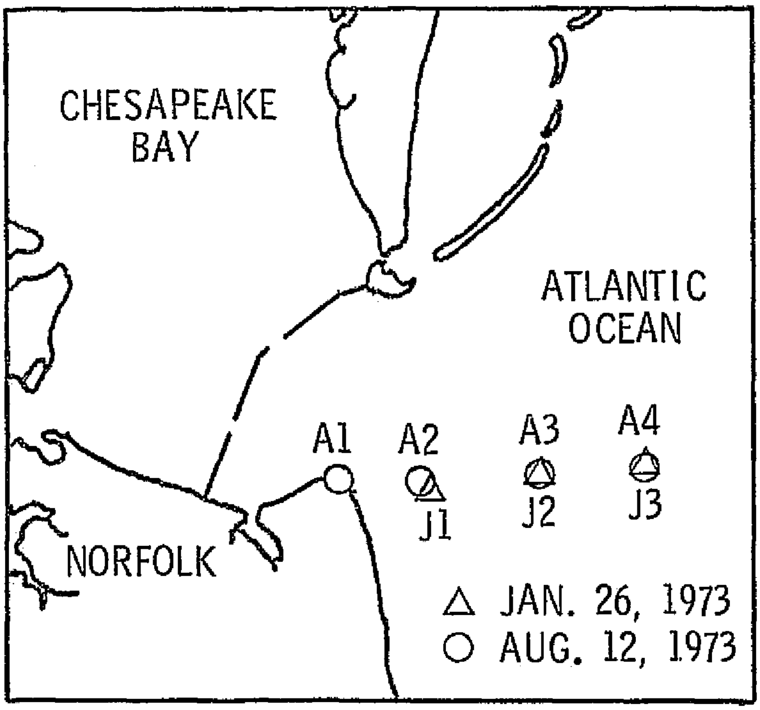

Figure 2. LINWOOD HOLTON Chesapeake Bay station locations.

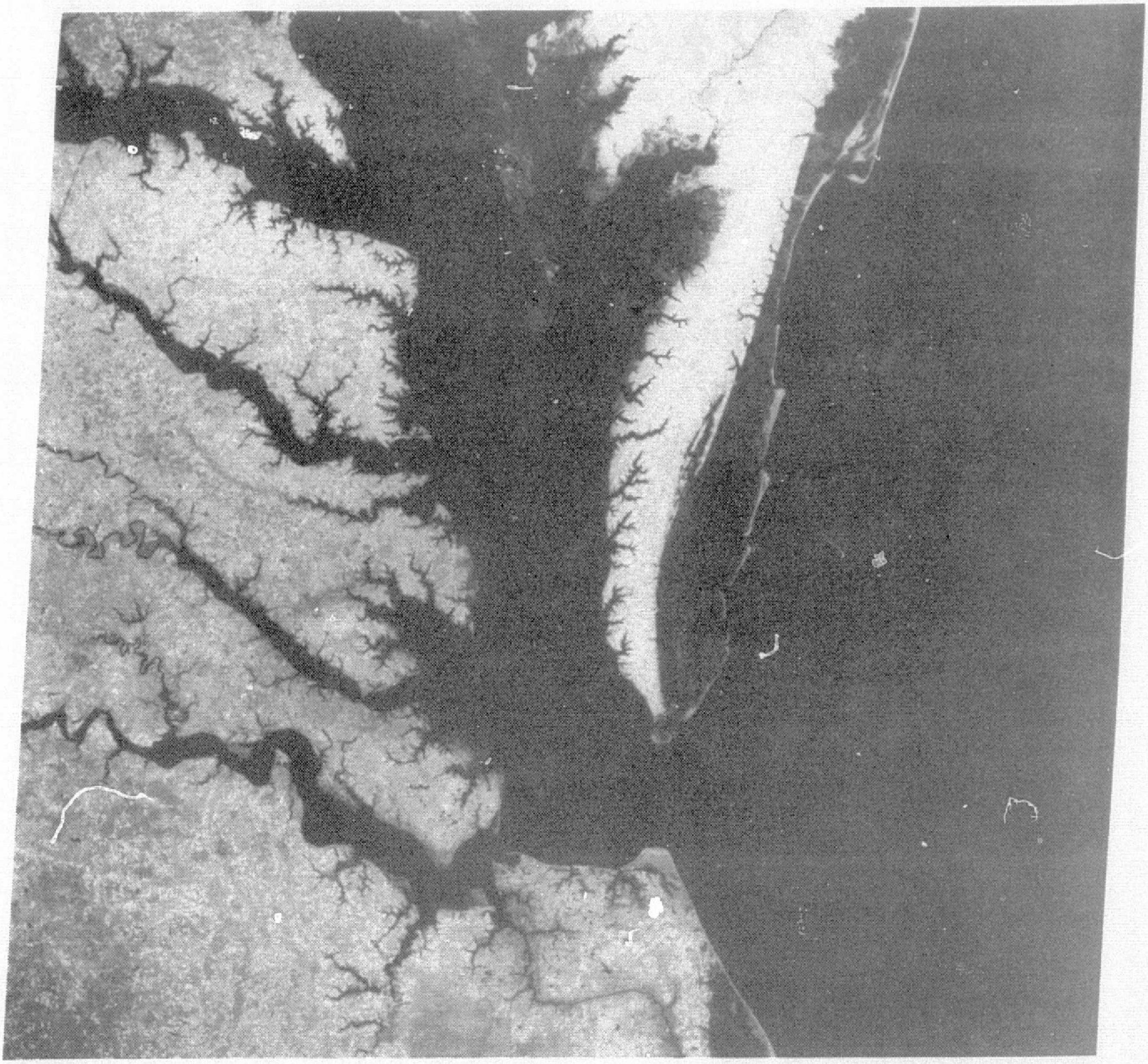

Figure 3. ERTS band 6 image of lower Chesapeake Bay area, August 12, 1973.

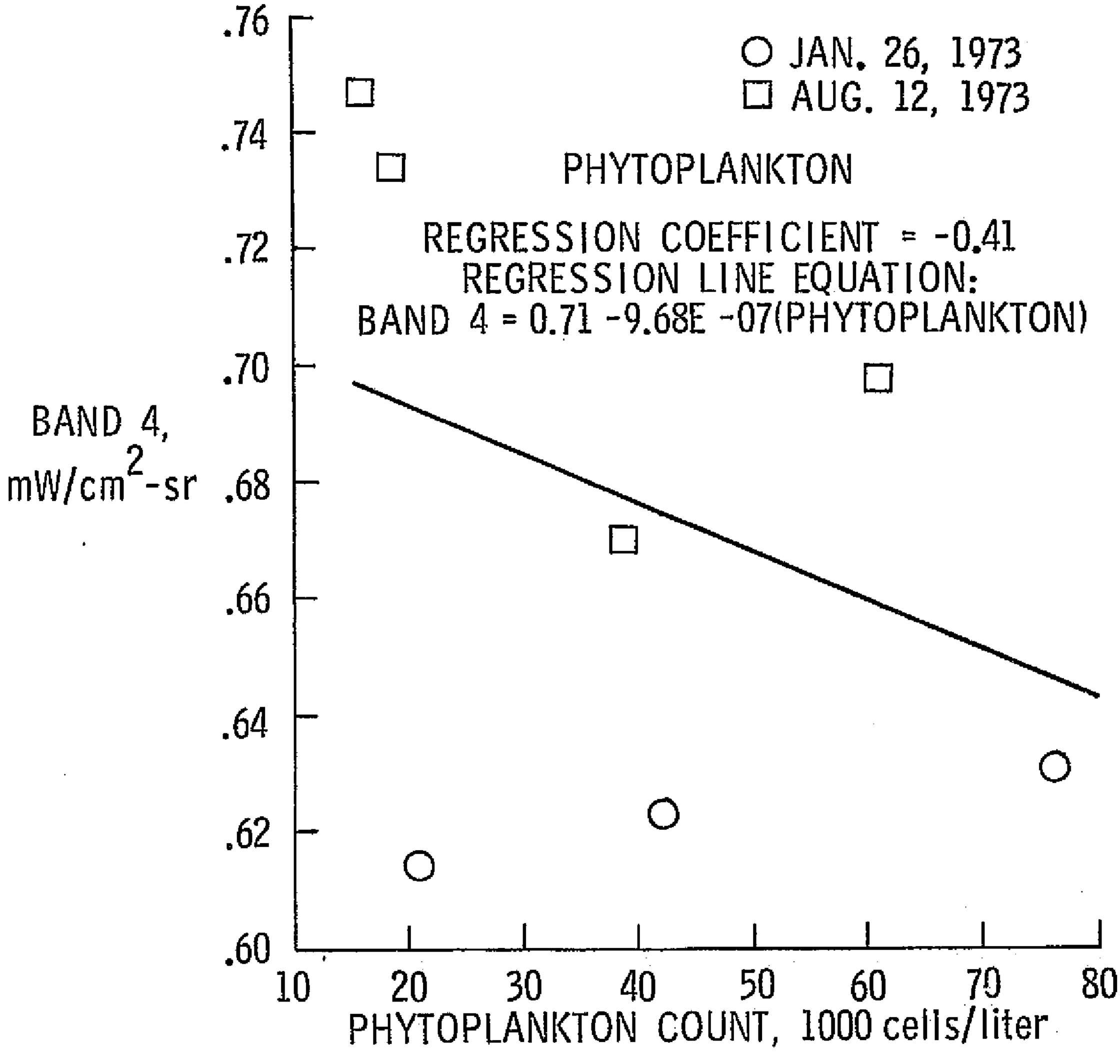

Figure 4. Band 4 radiance versus phytoplankton count.

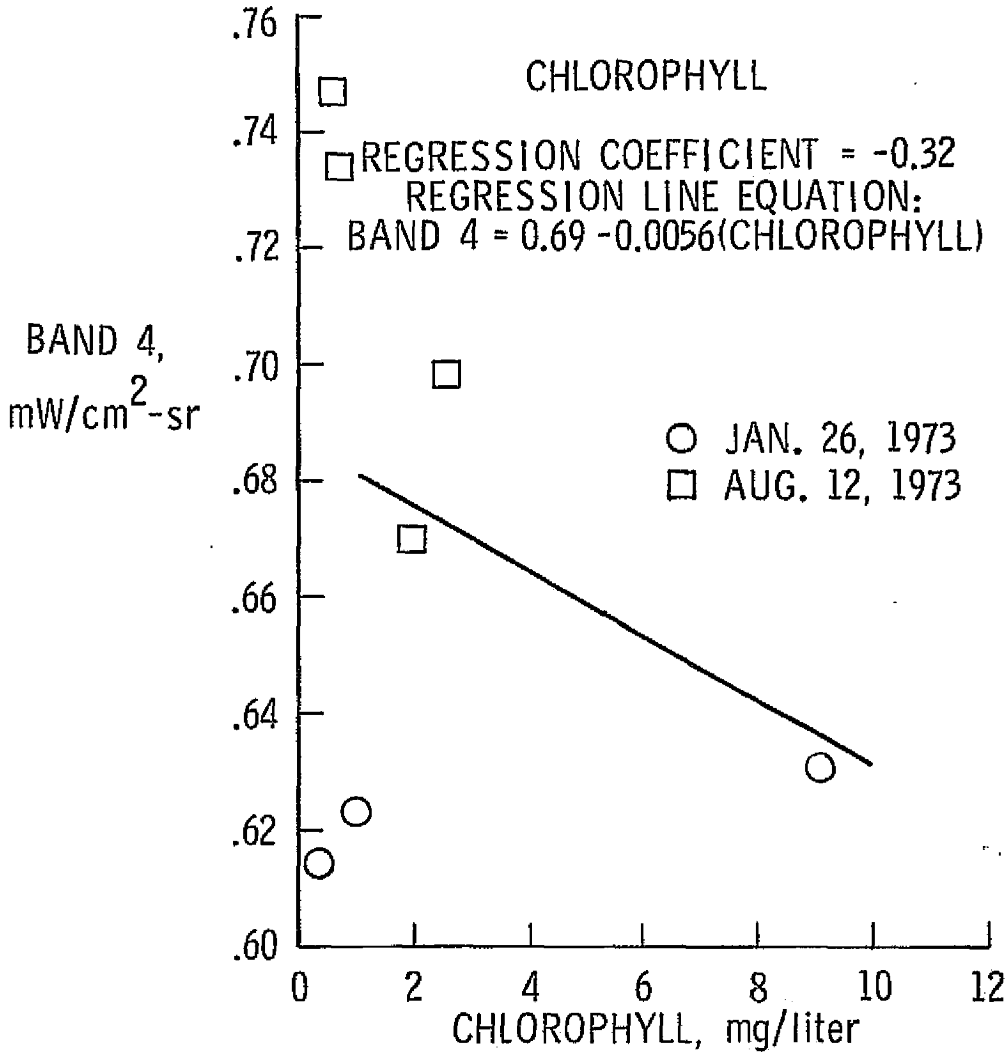

Figure 5. Band 4 radiance versus chlorophyll.

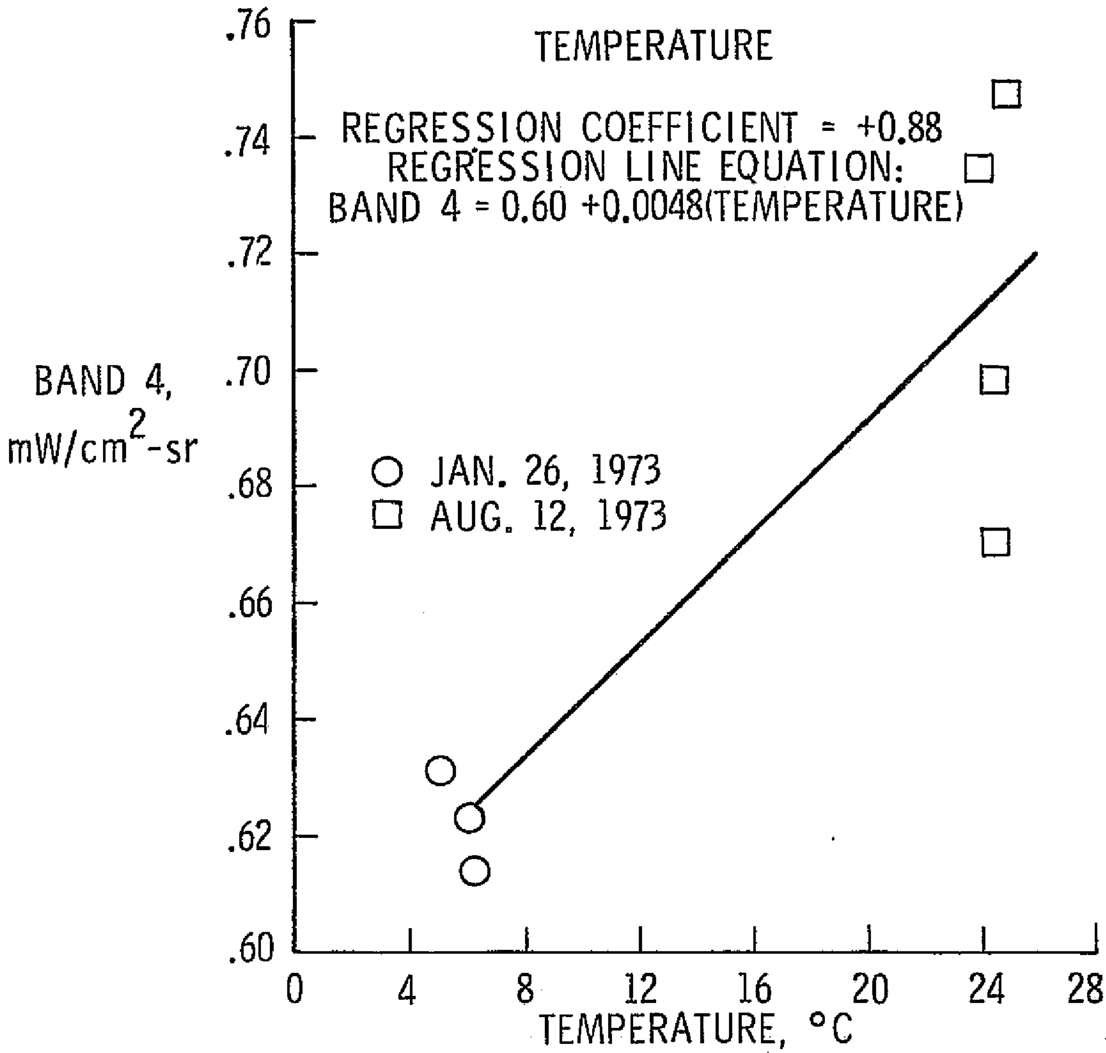

Figure 6. Band 4 radiance versus temperature.

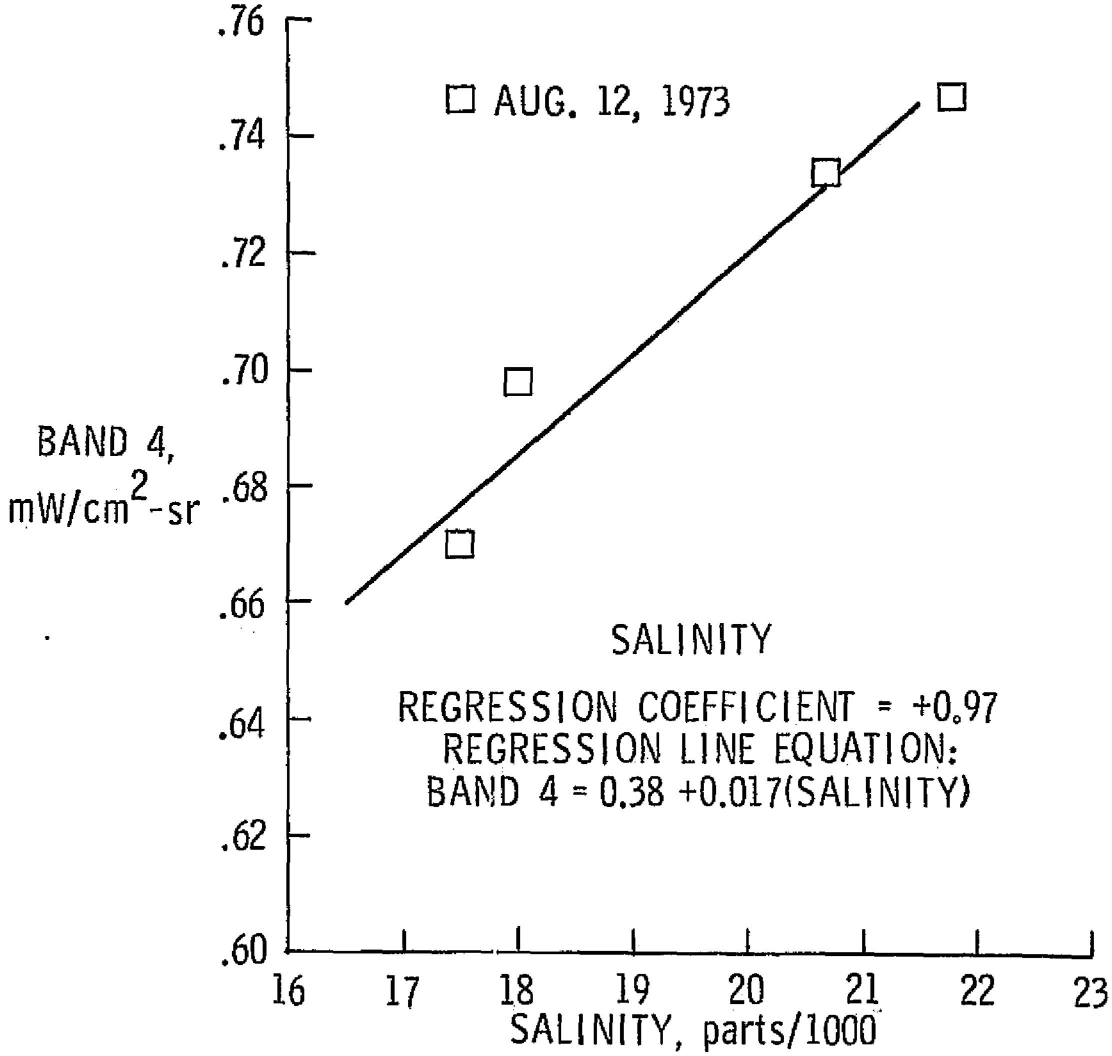

Figure 7. Band 4 radiance versus salinity.

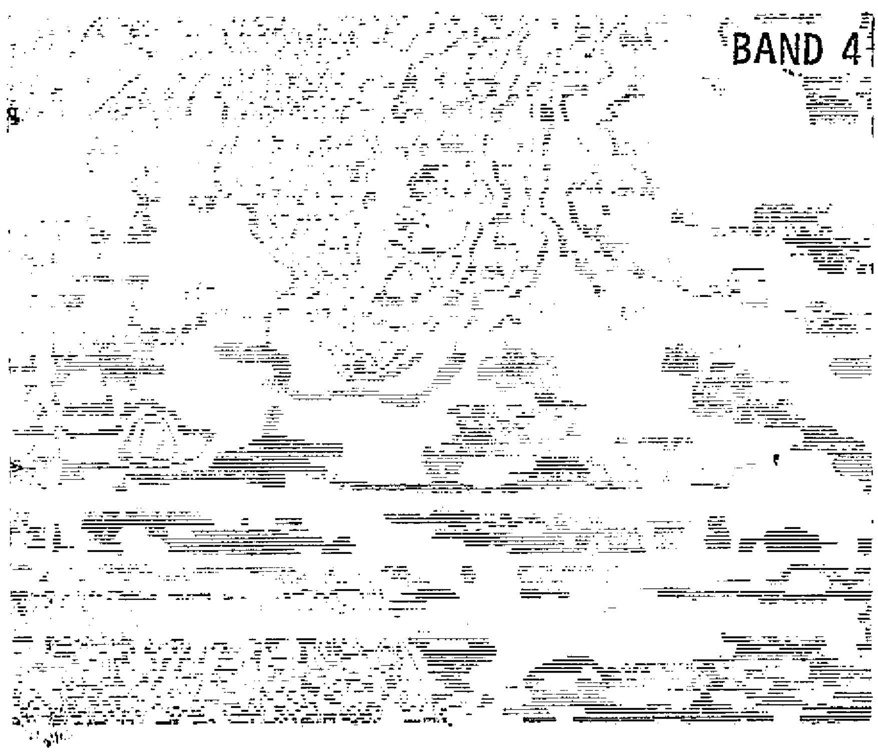

Figure 8. ERTS-1 band 4 isophot, August 12, 1973.

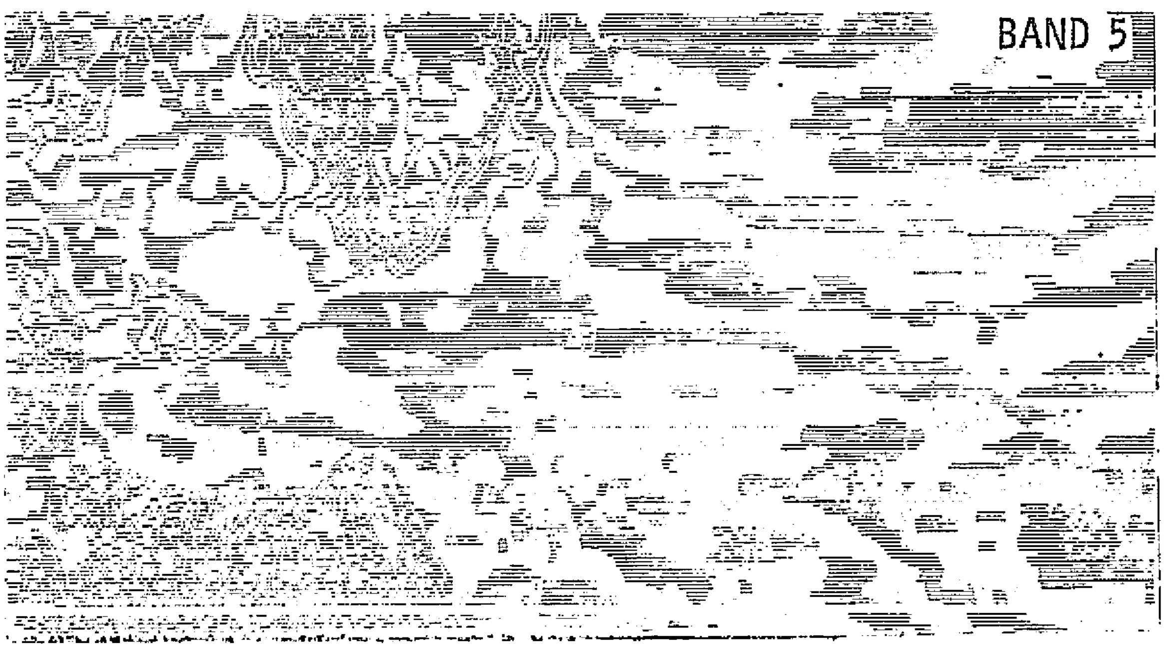

Figure 9. ERTS-1 band 5 isophot, August 12, 1973.

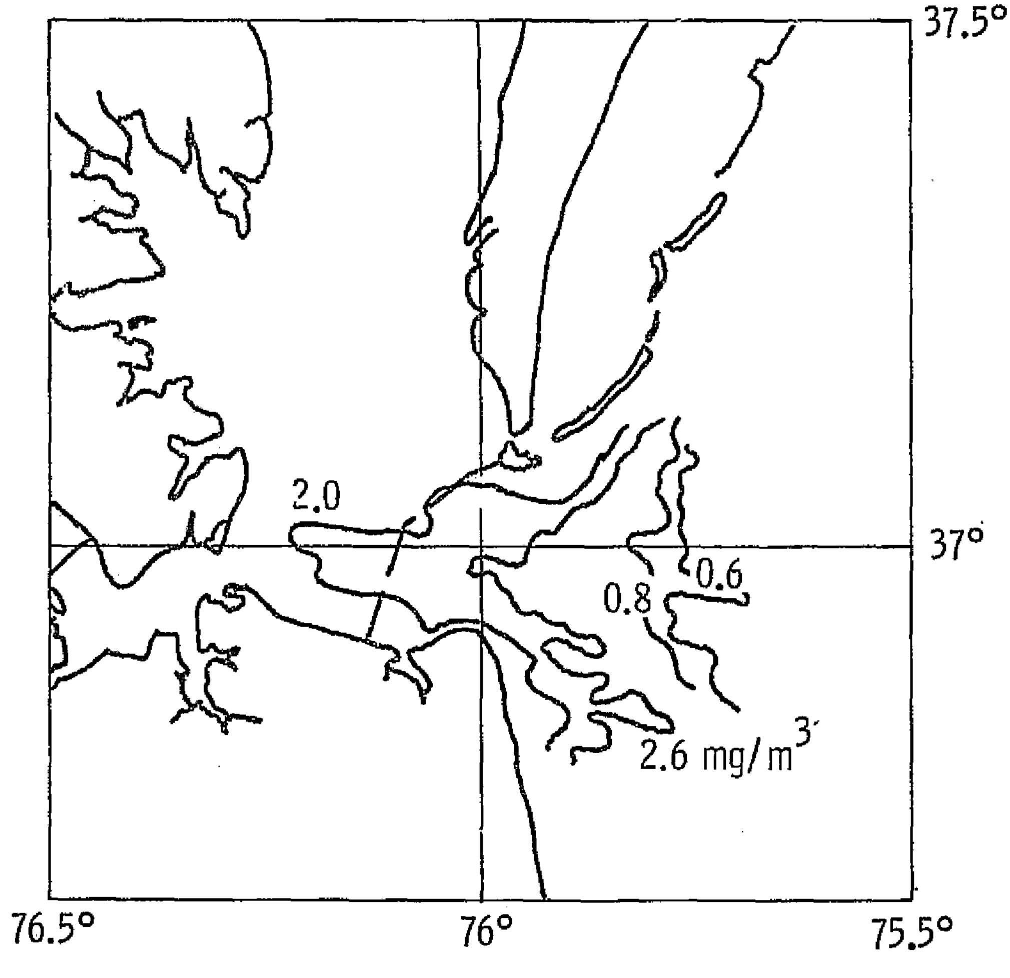

Figure 10. Chlorophyll contours from band 4 isophot, August 12, 1973.

Table 1. Phytoplankton identified at stations during DELAWARE II, 72-19 cruise.

Diatoms

Achnanthes longipes Agardh
Bacteriastrum sp. Shadbolt
Cerataulina bergonii H. Per.
Chaetoceros affinis Laud.
Chaetoceros compressus Laud.
Chaetoceros didymus Ehr.
Chaetoceros gracilis Schutt
Chaetoceros radicans Schutt
Chaetoceros subtilis Cleve
Climacodium frauenfeldianum Grun
Coscinodiscus sp. Ehr.
Coscinodiscus radiatus Ehr.
Cyclotella sp. Kutz.
Cyclotella glomerata Bachmann
Fragilaria construens Ehr.
Fragilaria crotonensis Kitt.
Leptocylindrus danicus Cl.
Melosira distans (Ehr.) Kutz
Melosira granulata (Ehr.) Ralfs
Melosira sulcata (Ehr.) Kutz
Navicula sp. Bory
Nitzschia closterium (Ehr.) W. Sm.
Nitzschia longissima (Breb.) Ralfs
Rhizosolenia alata Brightw.
Rhizosolenia fragilissima Berg. .
Rhizosolenia imbricata Schrod.
Rhizosolenia stolterfothii H. Per.
Skeletonema costatum (Grev.) Cleve
Synedra sp. Ehr.
Thalassionema nitzschioides Grun.
Thalassiosira aestivalis Gran.
Thalassiosira decipiens (Grun.) Jorg.
Thalassiosira gravida Cleve
Thalassiothrix frauenfeldii Grun.

Pyrrhophyta

Amphidinium sp. Clap. and Lach.
Ceratium extensum Gour.
Ceratium fusus Ehr.
Ceratium pentagonium Gourret
Ceratium teres Kofoid
Ceratium tripos Atlantica Osten.
Exuviaella apora Schiller
Gonyaulax sp. Diesing
Gymnodinium sp. Stein
Gymnodinium simplex Lohm.

(continued)

Table 1. Phytoplankton identified at stations during DELAWARE II, 72-19 cruise (concluded).

Pyrrhophyta (continued)

Peridinium granii Osten.
Peridinium monospinum Paulsen
Peridinium triqueta Stein
Peridinium trochoideum Stein
Prorocentrum micans Ehr.
Prorocentrum scutellum Schroeder

Cyanophyta

Trichodesmium thiebautii Gom.
Johannesbaptistia pellucida Taylor and Drouet
Oscillatoria sp. Vaucher

Silicoflagellates

Dictyocha fibula Ehr
Distephanus speculum Ehr.

Coccolithophores

Coccolithus huxleyi Kamptner
Cyclococcolithus leptoporus Kamptner
Discosphaera tubifera Ostenfeld
Gephyrocapsa oceanica Kamptner
Syracosphaera pulchra Lohmann

Table 2. Phytoplankton concentrations and chlorophyll values during the DELAWARE II, 72-19 cruise.

Station Number	Coastal or Open Sea	Phytoplankton Number cells/liter	Chlorophyll A mg/m^3
1	C	6,800	0.2150
2	0	6,000	0.1634
3	0	2,400	0.3784
5	0	9,800	0.1634
7	0	7,200	0.1118
8	0	7,000	0.0516
32	0	5,200	0.1806
33	0	6,000	0.1973
34	0	28,400	0.1118
35	0	13,200	0.1720
48	C	91,200	1.5480
49	C	150,200	2.2618
56	0	13,200	0.1978
57	0	7,200	0.1806
58	0	7,000	0.3268
59	0	11,200	0.1806
63	C	16,800	0.4730
65	0	12,800	0.1634
66	0	219,600	0.2457
67	0	439,600	0.4472
68	0	926,000	0.5246
76	C	1,514,400	8.1528
77	0	75,200	0.8428
84	0	13,600	0.2322
86	0	1,200	0.0688
93	0	16,400	0.1720
94	0	302,000	0.3956
95	0	1,600	0.0258
109	0	3,600	0.0258
110	0	4,000	0.0258

(continued)

Table 2. Phytoplankton concentrations and chlorophyll values during the DELAWARE II, 72-19 cruise (concluded).

Station Number	Coastal or Open Sea	Phytoplankton Number cells/liter	Chlorophyll A mg/m^3
111	0	2,000	0.1806
112	0	2,000	0.4472
114	0	72,000	0.1978
126	C	38,000	0.3612
128	0	21,200	0.3010
138	0	4,800	0.1376
139	0	3,600	0.0688
140	0	400	0.0688
142	C	3,000	0.1548

Table 3. Surface temperature and salinity values during DELAWARE II, 72-19 cruise.

Station Number	Latitude	Longitude	T, °C	S, °/oo
1	42° 00' N	70° 00' W	19.9	30.72
2	42° 00' N	69° 30' W	17.7	31.36
3	41° 30' N	69° 30' W	14.4	31.63
5	40° 30' N	69° 30' W	18.0	32.88
7	39° 30' N	69° 30' W	22.7	35.13
8	39° 00' N	69° 30' W	24.4	35.77
32	40° 30' N	71° 30' W	21.0	31.49
33	40° 00' N	71° 30' W	20.5	32.77
34	37° 30' N	71° 30' W	22.4	34.04
35	39° 00' N	71° 30' W	24.5	35.72
48	40° 39' N	73° 00' W	23.2	28.42
49	40° 30' N	73° 30' W	21.1	27.31
54	39° 31' N	74° 00' W	23.9	31.18
56	39° 00' N	73° 30' W	23.7	30.09
57	39° 00' N	73° 30' W	23.9	30.76
58	39° 00' N	73° 00' W	24.0	30.17
59	38° 30' N	73° 00' W	23.7	32.97
63	38° 00' N	74° 00' W	25.5	31.50
65	38° 00' N	73° 00' W	23.8	31.70
66	38° 00' N	73° 00' W	24.2	33.39
67	38° 00' N	72° 00' W	25.8	35.10
68	38° 00' N	71° 00' W	25.6	34.14
76	37° 00' N	75° 00' W	26.9	16.15
77	37° 00' N	75° 00' W	27.3	26.31
84	36° 00' N	75° 00' W	25.4	29.49
86	36° 02' N	73° 06' W	28.1	35.91
93	35° 00' N	75° 00' W	28.2	35.67
94	35° 00' N	75° 00' W	30.8	36.19
95	35° 00' N	74° 00' W	28.3	35.91
109	33° 30' N	74° 60' W	27.7	36.07

(continued)

Table 3. Surface temperature and salinity values during DELAWARE II, 72-19 cruise (concluded).

Station Number	Latitude	Longitude	T, °C	S, °/oo
110	33° 30' N	75° 00' W	29.1	36.06
111	33° 30' N	76° 00' W	28.9	35.86
112	33° 30' N	77° 00' W	28.0	35.26
114	33° 30' N	78° 00' W	27.1	35.16
126	32° 00' N	80° 30' W	28.6	34.62
128	32° 00' N	79° 30' W	28.0	36.00
138	30° 30' N	78° 00' W	28.2	36.07
139	30° 30' N	78° 59' W	28.8	36.08
140	30° 30' N	80° 00' W	28.7	36.17
142	30° 30' N	81° 00' W	26.1	35.79

Table 4. Phytoplankton identified at stations during ALBATROSS IV, 73-2 cruise.

Diatoms

Bacteriastrum delicatula Cleve
Bacteriastrum elongatum Cleve
Cerataulina bergonii Peragallo
Chaetoceros affinis Lauder
Chaetoceros pelagicus Cleve
Chaetoceros wighami Brightwell
Cyclotella sp. Kutzing
Hemiaulus hauckii Grunow
Leptocylindrus danicus Cleve
Melosira distans Kutzing
Melosira granulata Ralfs
Melosira sulcata Kutzing
Nitzschia closterium (Ehren.) W. Smith
Nitzschia pungens Atlantica Cleve
Rhizosolenia alata Brightwell
Rhizosolenia calcaravis Schultze
Rhizosolenia stolterfothii Peragallo
Skeletonema costatum (Grev.) Cleve
Thalassionema nitzschioides Grunow
Thalassiothrix longissima Cleve and Crunow
Thalassiothrix frauenfeldii Grunow

Pyrrhophyta

Amphidinium acutissimum Schiller
Exuviaella apora Schiller
Gymnodinium punctatum Pouchet
Gyrodinium ap. Kofoid and Swezy
Katodinium rotundatum Conrad
Oxytoxum laticeps Schiller
Oxytoxum longiceps Schiller
Oxytoxum variable Schiller
Peridinium brevipes Paulsen
Peridinium trochoideum Lemmermann
Peridinium minisculum Pavillard
Ceratium gallicum Kofoid
Ceratium lineatum Cleve

Cyanophyta

Oscillatoria sp. Vaucher
Trichodesmium hildebrantii Gomont
Anacystis sp. Meneghini

(continued)

Table 4. Phytoplankton identified at stations during ALBATROSS IV, 73-2 cruise (concluded).

Silicoflagellates	
	Dictyocha fibula Ehrenberg
	Distephanus speculum (Ehren.) Haeckel
Coccolithophores	
	Coccolithus huxleyi Kamptner
	Coccolithophora leptopora Kamptner
	Discosphaera tubifer Ostenfeld
	Rhabdosphaera stylifer Lohmann
	Syracosphaera pulchra Lohmann
	Calciosolenia murrayi Gran

Table 5. Surface temperature and salinity values during ALBATROSS IV, 73-2 cruise.

Station Number	Latitude	Longitude	T, °C	S, $^{o}/oo$
1	29° 00' N	71° 00' W	22.5	36.50
2	28° 00' N	71° 00' W	23.3	36.43
3	27° 00' N	71° 00' W	24.2	---
4	26° 00' N	71° 00' W	24.0	36.39
5	25° 00' N	71° 01' W	24.8	36.33
6	24° 00' N	71° 00' W	25.2	---
7	23° 00' N	71° 00' W	25.2	36.38
8	22° 00' N	71° 00' W	26.1	36.19
9	20° 40' N	71° 30' W	26.2	---
11	20° 11' N	72° 00' W	26.6	36.10
12	21° 00' N	72° 25' W	26.2	36.16
13	22° 00' N	72° 47' W	25.8	36.24
14	23° 00' N	73° 00' W	25.4	36.35
15	24° 00' N	73° 00' W	24.8	36.36
18	27° 00' N	73° 00' W	23.4	36.39
37	28° 02' N	77° 00' W	22.2	36.43
38	27° 00' N	77° 00' W	22.6	---
42	29° 00' N	78° 00' W	22.7	36.28
44	30° 00' N	78° 00' W	21.8	36.33
45	30° 00' N	79° 00' W	23.0	36.27
46	29° 30' N	79° 00' W	23.3	---
47	29° 00' N	79° 00' W	23.3	36.26
48	28° 30' N	79° 00' W	23.3	---
49	28° 00' N	79° 00' W	23.3	36.32
52	26° 40' N	79° 14' W	24.6	---
53	26° 13' N	79° 00' W	24.8	36.13

Table 6. Phytoplankton concentrations and chlorophyll values during ALBATROSS IV, 73-2 cruise.

Station Number	Transect Number	Phytoplankton Number cells/liter	Chlorophyll mg/m^3
1	1	7,600	0.07
3	1	4,800	0.06
5	1	47,200	0.03
7	1	11,200	0.02
9	1	5,600	0.02
11	1	14,000	0.05
13	1	9,600	0.02
15	1	15,600	0.08
37	2	8,400	0.22
45	2	27,200	0.42
47	2	18,800	0.27
49	2	16,400	0.26
53	2	1,200	0.12

Table 7. Surface salinity values at stations in the Chesapeake Bay entrance.

Date	Stations, ppt 1	2	3	4
Apr 26, 1973	11.5	13.2	14.8	20.6
May 14, 1973	14.2	14.4	20.8	20.8
Jun 1, 1973	14.4	15.2	21.6	21.4
Jun 19, 1973	14.6	17.4	22.4	21.9
Jul 7, 1973	16.9	17.0	22.3	20.2
Jul 25, 1973	17.8	19.1	21.3	21.5
Aug 12, 1973	17.5	18.0	20.7	21.8
Aug 30, 1973	17.4	17.9	19.4	21.4
Sep 17, 1973	16.8	17.5	18.0	20.7

Table 8. Surface temperature values at stations in the Chesapeake Bay entrance.

Date	Stations, °C			
	1	2	3	4
Apr 26, 1973	14.5	14.2	14.2	13.1
May 14, 1973	18.0	18.0	17.0	17.3
Jun 1, 1973	20.0	19.8	18.5	20.8
Jun 19, 1973	22.0	21.5	21.5	22.0
Jul 7, 1973	24.5	24.0	22.0	24.5
Jul 25, 1973	24.0	24.0	--	--
Aug 12, 1973	24.5	24.5	24.0	25.0
Aug 30, 1973	24.5	24.5	24.4	24.6
Sep 17, 1973	24.5	24.5	24.5	24.0

Table 9. Dominant phytoplankters[1] observed at the Chesapeake Bay entrance.

Species	Jan	Apr	May	Jun	Jul	Aug	Sep
	Months 1973						
A. Diatoms							
Asterionella japonica		B	B				
Cerataulina bergonii			B	B			
Chaetoceros spp.		B		A	B		
Cyclotella spp.		B	B				B
Leptocylindrus danicus					B		
Melosira spp.	A	A					
Nitzschia pungens Atlantica			B	A	A		
Rhizosolenia spp.			B	B	B		
Skeletonemia costatum	X	B	B	B	A	B	X
Thalassionema nitzschioides	B			A			B
Thalassiosira nordenskioldii	B				B		
B. Pyrrhophyceans							
Ceratium spp.					B		A
Exuviaella spp.	B	A	A				
Peridinium spp.	B				B		
Provocentrum micans	B		B		B		B

[1] A Dominant species
B Sub-dominant
X Present

Table 10. Total chlorophyll values and phytoplankton for the Chesapeake Bay entrance.

Date 1973	Station Number	Chlorophyll mg/m^3	Phytoplankton, Number cells/liter × 10^2			
			Diatoms	Pyrrhophyceans	Other	Total
Jan 26	1	9.07	336	426	--	762
	2	1.01	278.4	144	--	422.4
	3	0.35	109	100.8	--	209.8
Apr 26	1	1.95	21,496	11,112	4,448	37,056
	2	1.35	14,672	6,960	5,920	27,552
	3	2.51	12,091	1,302	9,258	22,651
	4	0.44	2,165	71	880	3,116
May 14	1	6.17	30,496	5,584	24,672	60,752
	2	6.36	29,760	2,784	12,512	45,072
	3	2.42	4,704	1,888	1,920	8,512
	4	2.51	3,424	192	3,524	7,136
Jun 1	1	2.18	13,392	160	400	13,952
	2	0.96	13,693	176	193	14,062
	3	0.81	2,640	123	158	2,921
	4	0.30	1,504	80	1,488	3,072
Jun 19	1	1.01	21,280	160	528	22,368
	2	1.60	19,488	320	--	19,808
	3	0.95	2,112	32	64	2,208
	4	0.56	1,408	256	288	1,952
Jul 7	1	1.71	8,931	352	592	9,880
	2	1.17	7,308	224	320	7,852
	3	0.63	14,576	48	144	14,768
	4	0.79	7,856	112	208	8,166
Jul 25	1	1.31	3,008	160	416	3,584
	2	2.19	5,008	128	352	5,568
	3	0.73	6,020	32	--	6,058
	4	0.68	5,792	128	96	6,016
Aug 12	1	1.96	220	122	46	388
	2	2.56	328	201	82	611
	3	0.76	88	92	6	186
	4	0.64	74	84	2	160
Aug 30	1	1.61	3,240	540	80	3,860
	2	1.72	3,400	630	70	4,100
	3	0.82	680	110	30	820
	4	0.62	520	180	40	740
Sep 17	1	1.36	1,202	210	68	1,480
	2	1.73	910	40	10	960
	3	1.79	1,040	70	46	1,156
	4	0.895	420	220	12	652

Table 11. Correlation of each water parameter with the other parameters for the three cruises.

DELAWARE II

		1	2	3	4
1	Phytoplankton	1.0			
2	Chlorophyll	.82	1.0		
3	Temperature	.13	.03	1.0	
4	Salinity	-.56	-.81	.32	1.0

LINWOOD HOLTON

		1	2	3	4
1	Phytoplankton	1.0			
2	Chlorophyll	.46	1.0		
3	Temperature	-.56	-.28	1.0	
4	Salinity	-.63	-.53	.33	1.0

ALBATROSS IV

		1	2	3	4
1	Phytoplankton	1.0			
2	Chlorophyll	.21	1.0		
3	Temperature	-.11	-.68	1.0	
4	Salinity	.14	.15	-.42	1.0

Table 12. Water sample analyses at the Chesapeake Bay stations.

Date	Station Number	Longitude	Latitude	Chlorophyll mg/m^3	Temperature (°C)	Salinity (°/oo)	Phytoplankton no./liter
Jan 26, 1973	1	75° 55.1' W	36° 56.8' N	9.079	5.0		76,200
	2	75° 48.6' W	36° 57.8' N	1.016	6.0		42,000
	3	75° 42.4' W	36° 58.7' N	0.359	6.2		20,900
Aug 12, 1973	1	76° 04.4' W	36° 57.6' N	1.966	24.5	17.5	38,800
	2	75° 55.7' W	36° 57.0' N	2.564	24.5	18.0	61,100
	3	75° 48.6' W	36° 58.0' N	0.764	24.0	20.7	18,600
	4	75° 42.3' W	36° 58.9' N	0.643	25.0	21.8	16,000

Table 13. Station radiance values from ERTS-1 photography at the Chesapeake Bay entrance stations.

Date	Station Number	Radiance (mW/cm^2 - sr) Band 4	Band 5	Band 6	Band 7
Jan 26, 1973	1	.287	.079	.000	.000
	2	.283	.073	.000	.000
	3	.279	.040	.000	.000
Aug 12, 1973	1	.549	.222	.088	--
	2	.572	.252	.108	--
	3	.601	.277	.119	--
	4	.612	.281	.116	--

Table 14. Correlation between independent variables at the Chesapeake Bay stations.

Jan 26, 1973

		1	2	3	4
1	Chlorophyll	1.00			
2	Temperature	-1.00	1.00		
3	Phytoplankton	.95	-.97	1.00	
4	Salinity	--	--	--	--

Aug 12, 1973

		1	2	3	4
1	Chlorophyll	1.00			
2	Temperature	-.05	1.00		
3	Phytoplankton	.98	-.05	1.00	
4	Salinity	-.92	.22	-.84	1.00

TOTAL

		1	2	3	4
1	Chlorophyll	1.00			
2	Temperature	-.38	1.00		
3	Phytoplankton	.85	-.32	1.00	
4	Salinity	--	--	--	--

Table 15. Correlation between ERTS MSS bands and chlorophyll and temperature on January 26, 1973 and August 12, 1973 for LINWOOD HOLTON stations.

Chlorophyll

MSS Band(s)	Jan 26, 1973	Aug 12, 1973	Total
4	.90	-.82	-.32
5	.67	-.74	-.20
6	0.00	-.62	-.37
6/5	0.00	-.07	-.35
6/4	0.00	-.45	-.36
5/4	.65	-.65	-.15

Temperature

MSS Band(s)	Jan 26, 1973	Aug 12, 1973	Total
4	-.93	.16	.88
5	-.73	.06	.93
6	0.00	-.09	.98
6/5	0.00	-.44	1.00
6/4	0.00	-.21	.99
5/4	-.71	-.03	.92

Phytoplankton

MSS Band(s)	Jan 26, 1973	Aug 12, 1973	Total
4	.99	-.70	-.41
5	.87	-.61	-.21
6	0.00	-.47	-.35
6/5	0.00	.10	-.30
6/4	0.00	-.29	-.32
5/4	.86	-.50	-.12

Salinity

MSS Band(s)	Aug 12, 1973
4	.97
5	.92
6	.82
6/5	.30
6/4	.68
5/4	.85